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**Mouchet et al.**

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- (54) **ELECTRICAL CURRENT TRANSDUCER**
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- (58) **Field of Classification Search**  
None  
See application file for complete search history.

- (56) **References Cited**  
**U.S. PATENT DOCUMENTS**  
4,487,812 A 12/1984 Kawasaki  
6,580,348 B1 6/2003 Hundt  
2008/0094162 A1\* 4/2008 Schaerrer ..... G01R 15/185  
336/178

(\*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 31 days.

- FOREIGN PATENT DOCUMENTS**  
EP 1617228 1/2006  
EP 2515125 10/2012

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§ 371 (c)(1),  
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PCT Pub. Date: **Apr. 26, 2018**

**OTHER PUBLICATIONS**  
International Search Report and Written Opinion issued by the European Patent Office, dated Feb. 5, 2018, for International Patent Application No. PCT/EP2017/076195; 12 pages.

\* cited by examiner

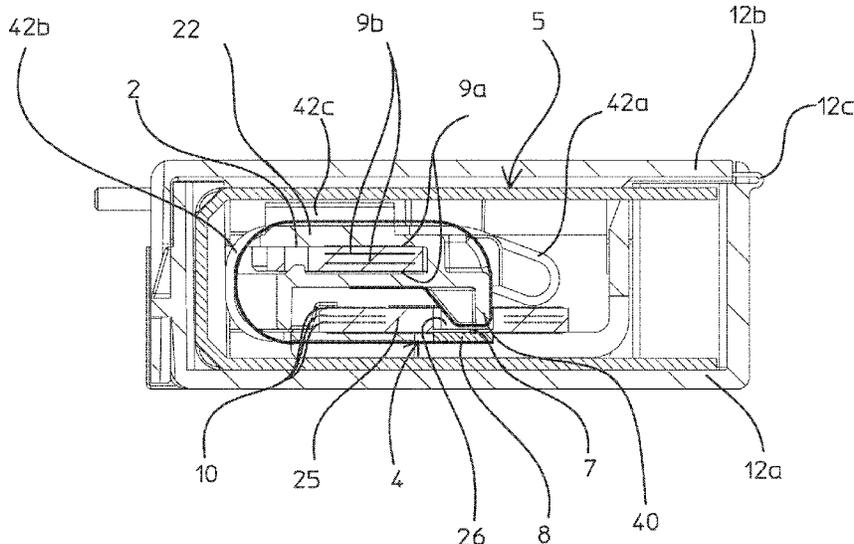
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- (57) **ABSTRACT**  
A current transducer including a housing comprising an outer casing, a magnetic circuit core configured to encircle at least one primary conductor, and a magnetic field detector positioned in a magnetic circuit gap of the magnetic circuit core. The housing further includes an inner support part comprising a main body portion and a magnetic core support portion. The magnetic circuit core is in the form of a thin strip of amorphous material supported on the main body portion and magnetic core support portion, the magnetic circuit gap being formed between overlapping ends of the strip.

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**G01R 15/18** (2006.01)  
**G01R 19/00** (2006.01)
- (52) **U.S. Cl.**  
CPC ..... **G01R 15/183** (2013.01); **G01R 19/0092** (2013.01)

**15 Claims, 8 Drawing Sheets**



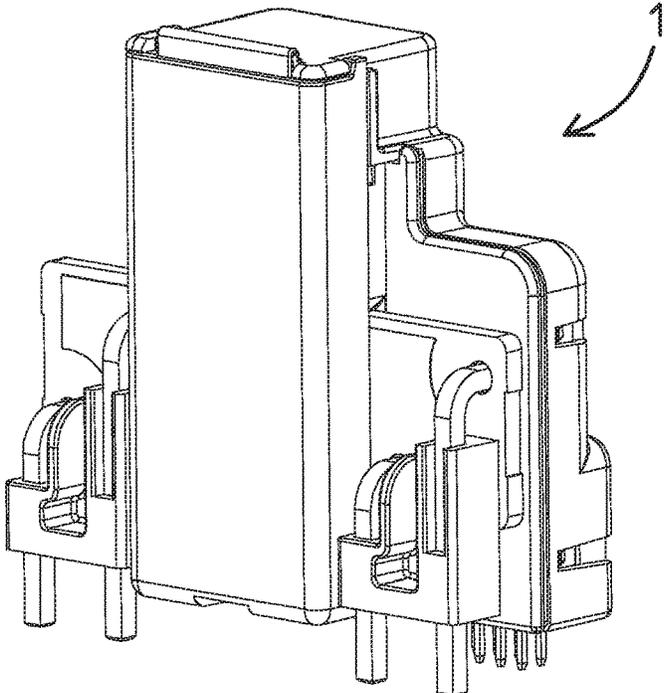


Fig. 1b

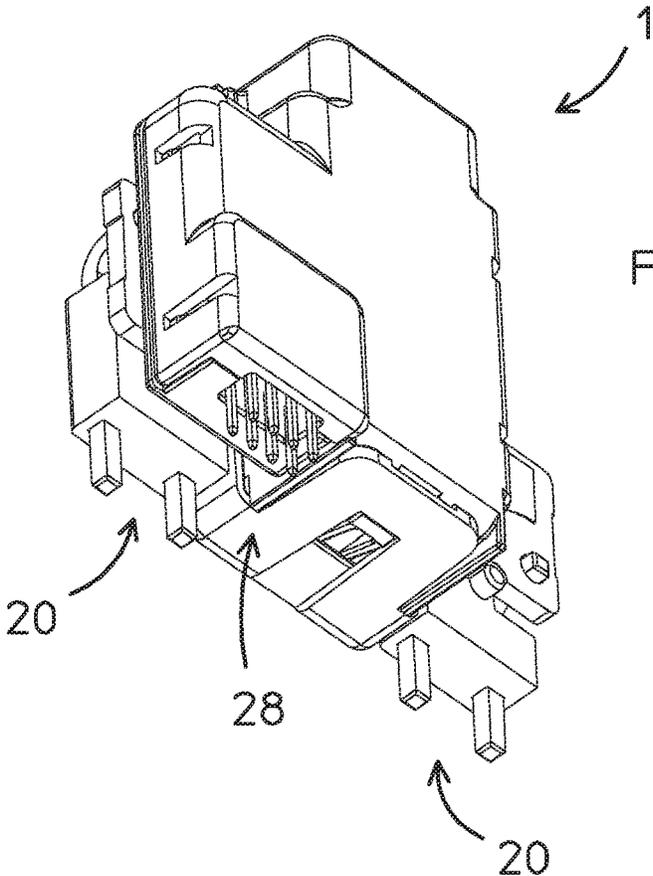
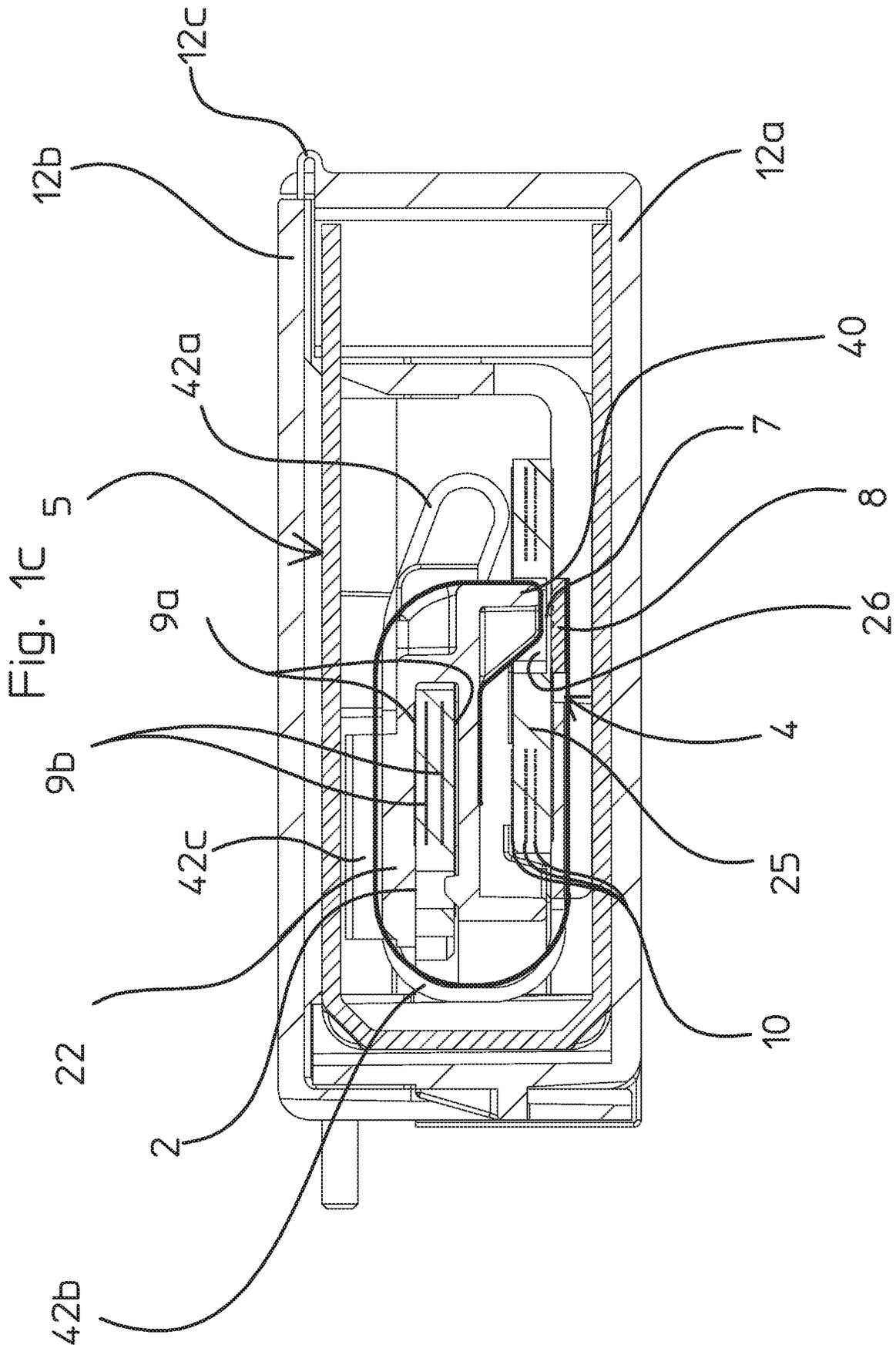
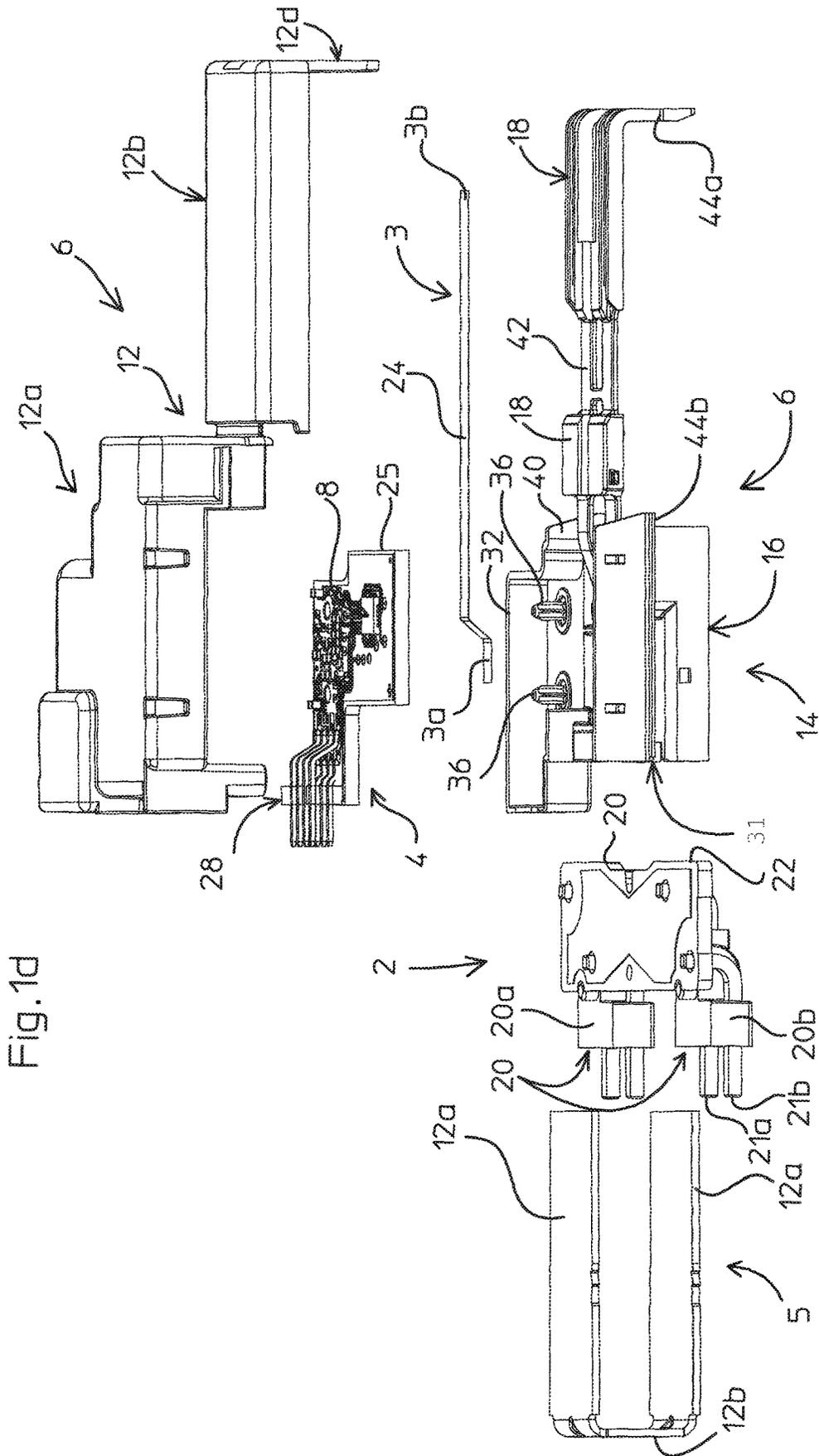


Fig. 1a





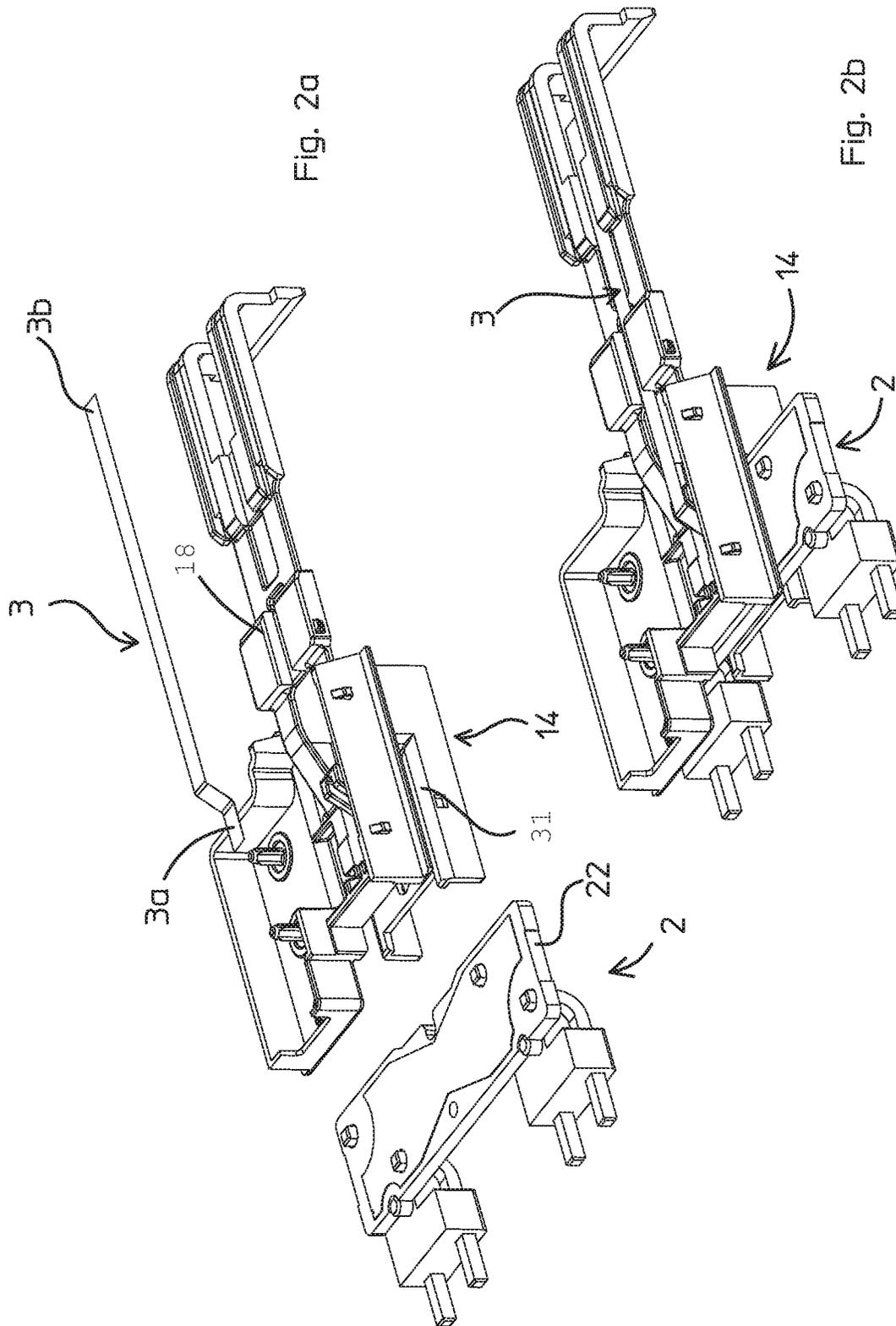


Fig. 2a

Fig. 2b

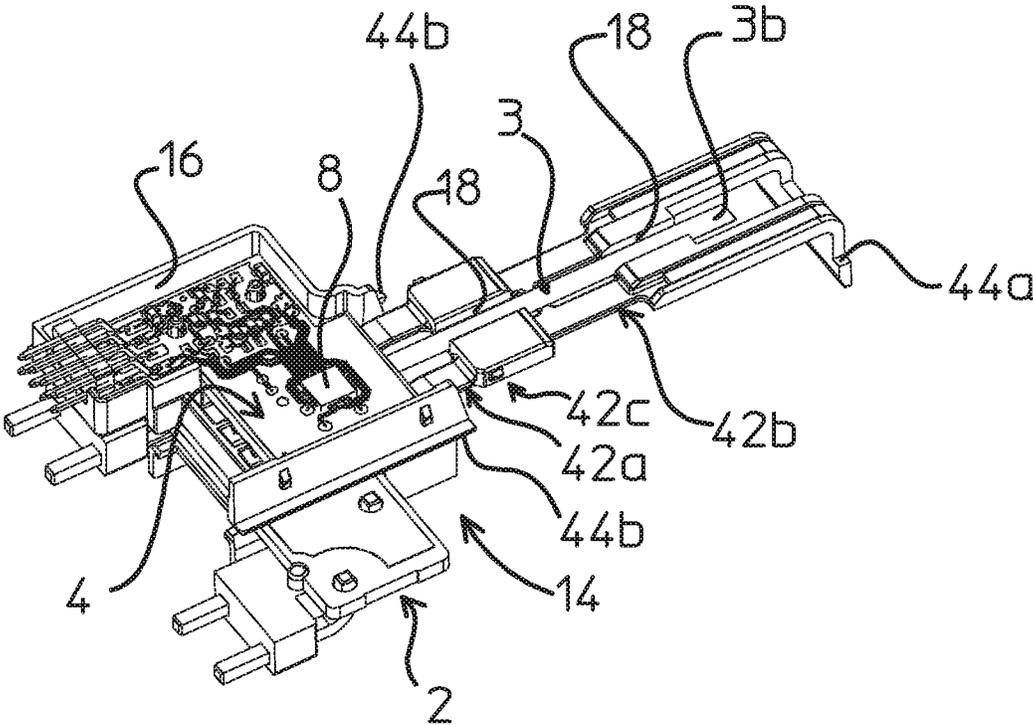


Fig. 2c

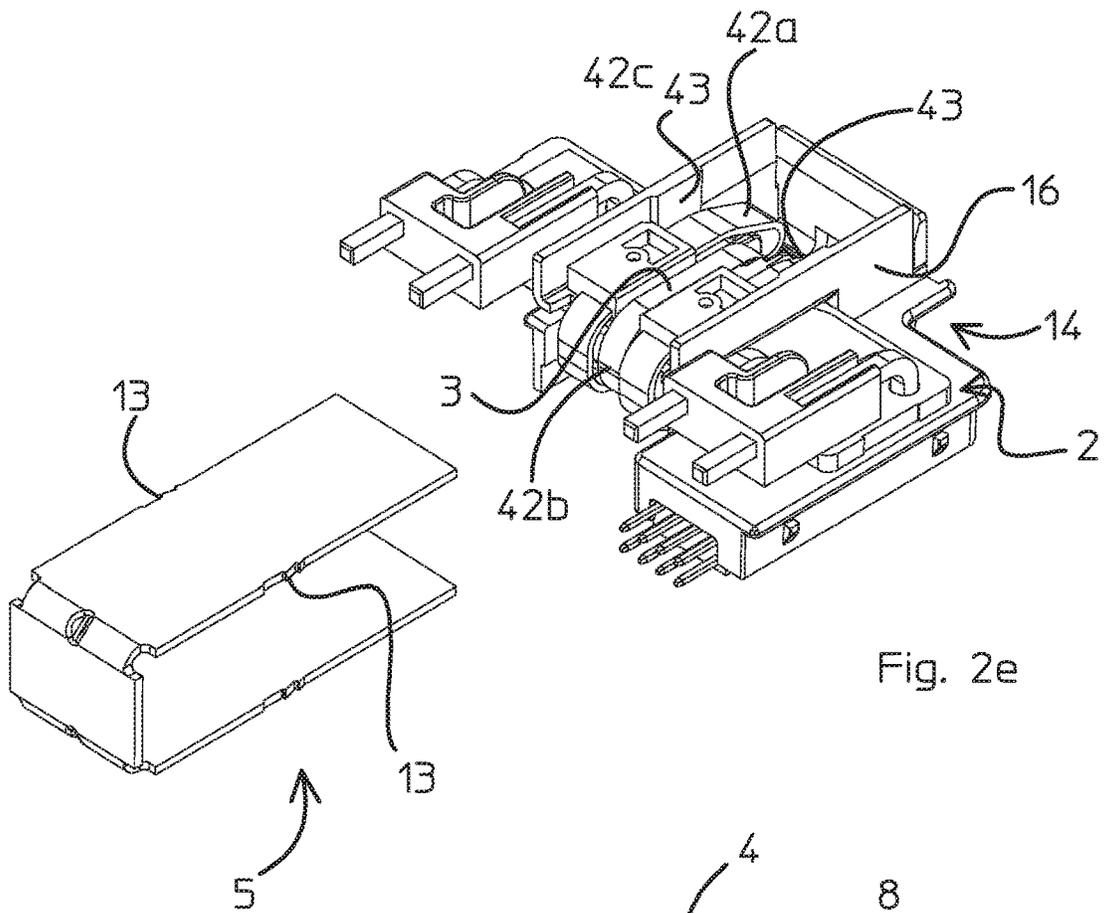


Fig. 2e

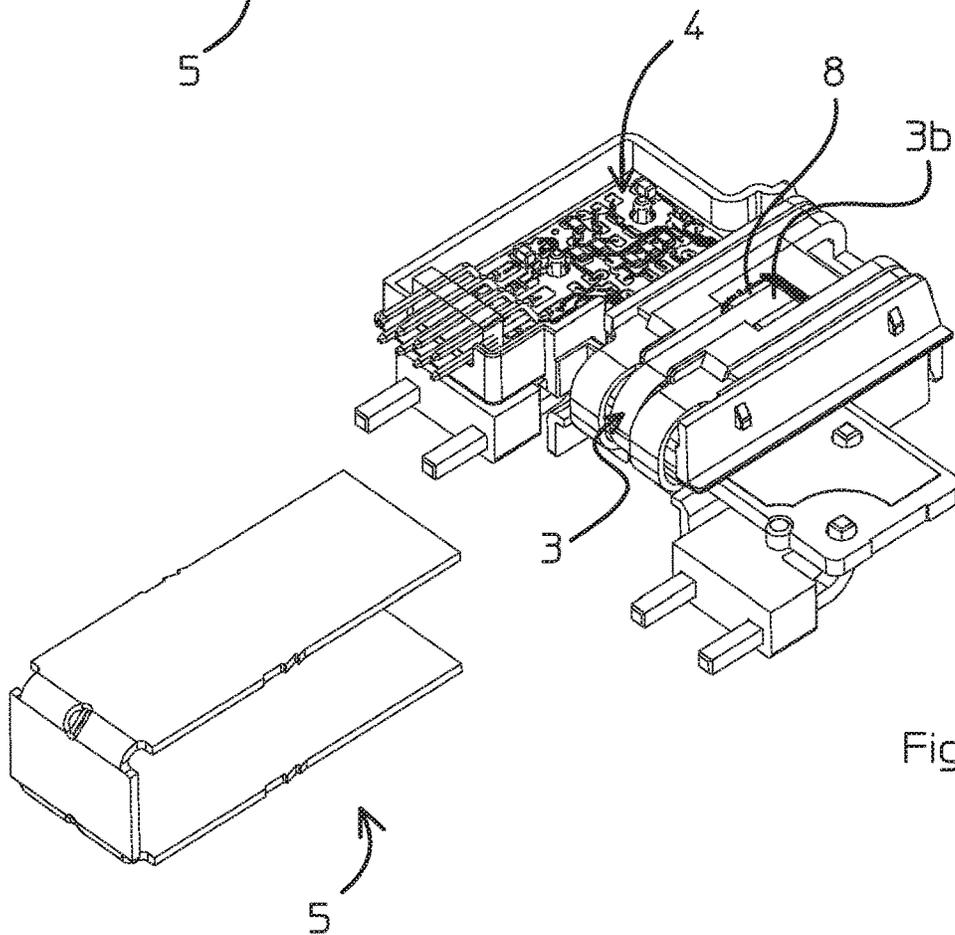


Fig. 2d

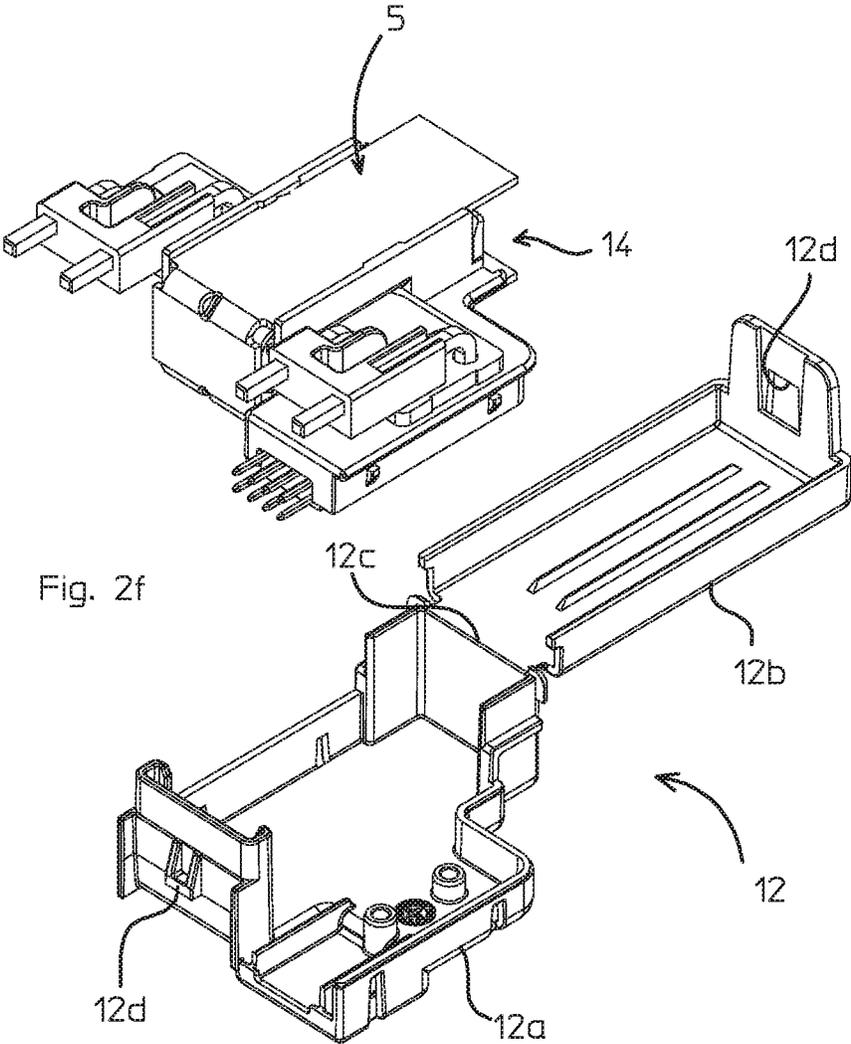
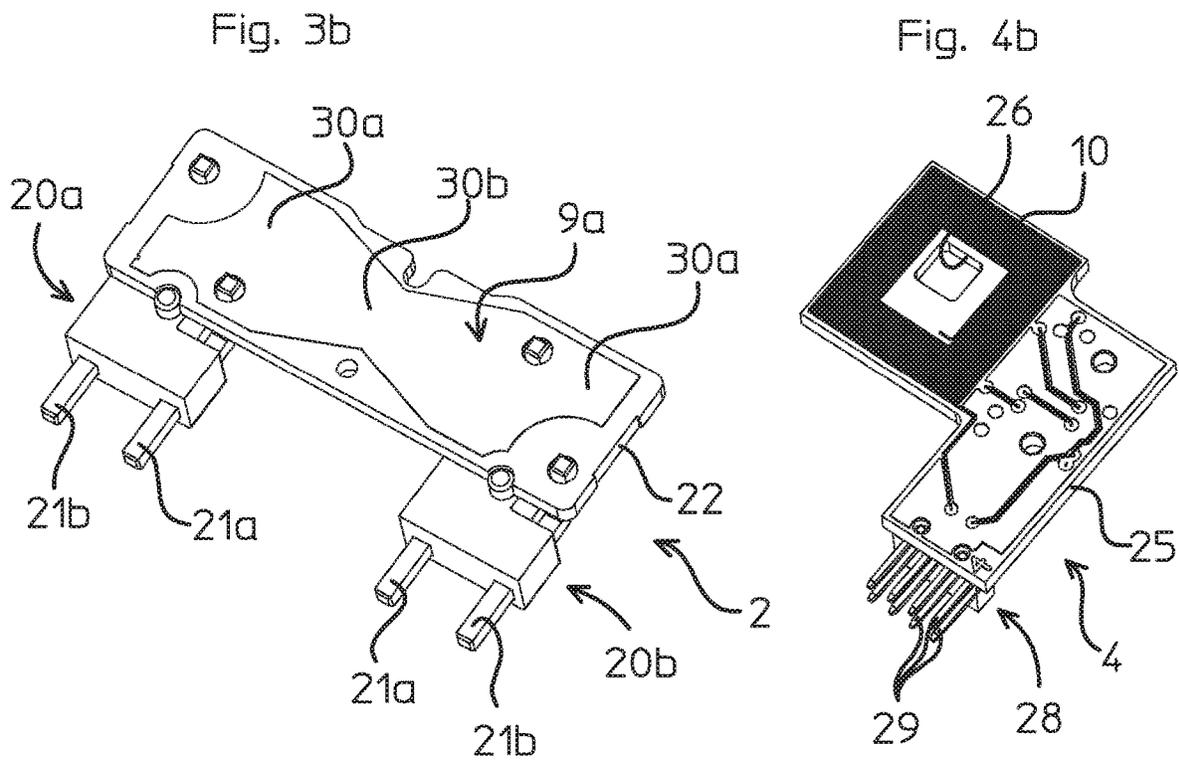
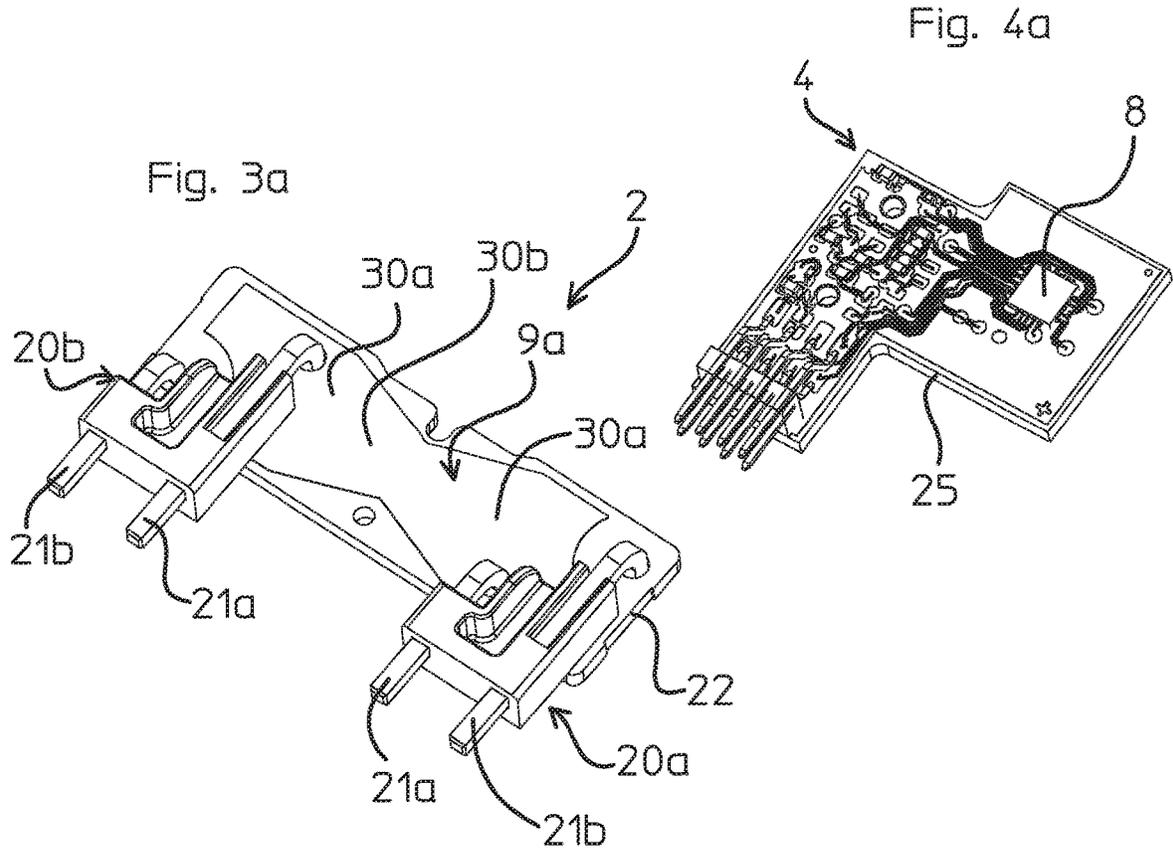


Fig. 2f



## ELECTRICAL CURRENT TRANSDUCER

## CROSS-REFERENCE TO RELATED APPLICATIONS

The present application is a national stage entry of International (PCT) Patent Application Number PCT/EP2017/076195, filed Oct. 13, 2017, which in turn claims priority to European Patent Application No. 16194452.5, filed Oct. 18, 2016, the subject matter of which are expressly incorporated herein by reference.

The present invention relates to an electrical current transducer for measuring a differential current, in particular to detect a residual or leak current.

There is a continuous desire to reduce manufacturing costs while increasing the performance and reliability of current transducers, which may include aspects such as measurement accuracy, large measurement operating range, reduced sensitivity to disturbance by external magnetic fields, manufacturing repeatability, stability over time and usage, and robustness. One of the main factors in the manufacturing cost of a current transducer is in the assembly of the components forming the transducer.

It is an object of this invention to provide an electrical current transducer that is accurate, reliable and robust, yet economical to manufacture.

It is advantageous to provide a closed-loop electrical current transducer that is simple to assemble and that has few components.

It is advantageous to provide an electrical current transducer that is robust and stable over time.

It is advantageous to provide an electrical current transducer that is compact.

Various objects of this invention have been achieved by providing the current transducer according to claim 1.

Disclosed herein is a current transducer including a housing comprising an outer casing, a magnetic circuit core configured to encircle at least one primary conductor, and a magnetic field detector positioned in a magnetic circuit gap of the magnetic circuit core. The housing further includes an inner support part comprising a main body portion and a magnetic core support portion. The magnetic circuit core comprises at least one strip of amorphous material with a magnetic reluctance smaller than the reluctance of the magnetic circuit gap and having a thickness less than 0.1 mm supported on the main body portion and magnetic core support portion, the magnetic circuit gap being formed between overlapping ends of the strip.

In an advantageous embodiment, the main body portion and the magnetic core support portion are connected via hinge portions configured to allow the magnetic core support portion to wrap around the main body portion.

In an advantageous embodiment, the hinge portions are flexible webs integrally formed with the main body portion and magnetic core support portion.

In an advantageous embodiment, the transducer includes a primary circuit unit comprising a first circuit board lodged in the main body portion of the inner support part and at least one conductive trace on the circuit board constituting a portion of the at least one primary conductor.

In an advantageous embodiment, the first circuit board comprises a plurality of circuit traces on different layers of the first circuit board, forming said at least one primary conductor.

In an advantageous embodiment, the transducer comprises at least two primary conductors configured to carry

currents flowing in opposing directions, wherein the transducer is configured for a differential current measurement.

In an advantageous embodiment, the circuit traces on different layers overlap each other by at least 80%, seen in a direction orthogonal to the circuit board.

In an advantageous embodiment, the one or more conductive traces of the one or more primary conductor portions comprise a mid-portion of narrower width than end portions.

In an advantageous embodiment, the transducer comprises a secondary circuit unit comprising a second circuit board lodged in the main body portion of the inner support part, the magnetic field detector being mounted on the second circuit board.

In an advantageous embodiment, the secondary circuit unit comprises a compensation coil in the form of windings of a circuit trace on one or more layers of the second circuit board around the magnetic field detector.

In an advantageous embodiment, the second circuit board comprises a recess or orifice below the magnetic field detector configured to allow one end of the magnetic circuit core to be positioned therein.

In an advantageous embodiment, the magnetic core support portion comprises a slot in which the magnetic circuit strip is positioned.

In an advantageous embodiment, the transducer comprises a magnetic shield having a U shape inserted over the magnetic circuit and supported on the main body portion of the inner support part.

In an embodiment, the magnetic circuit core has a thickness of less than 0.03 mm.

In an advantageous embodiment, the magnetic core support portion and main body portion comprise complementary latch portions to fix together the portions in the wrapped around position.

Further objects and advantageous aspects of the invention will be apparent from the claims, the following detailed description, and drawings in which:

FIGS. 1a and 1b are views in perspective of an electrical current transducer according to an embodiment of the invention;

FIG. 1c is a cross-sectional view of the current transducer of FIGS. 1a, 1b;

FIG. 1d is an exploded perspective view of the current transducer of FIG. 1a;

FIGS. 2a to 2f are views in perspective showing assembly of components forming the current transducer of FIGS. 1a-1d;

FIGS. 3a and 3b are perspective views of a primary circuit unit of a current transducer according to an embodiment of the invention;

FIGS. 4a and 4b are perspective views of a secondary circuit unit of a current transducer according to an embodiment of the invention.

Referring to the Figures, an electrical current transducer 1 according to an embodiment of this invention comprises a primary circuit unit 2, a secondary circuit unit 4 and a housing 6. The primary circuit unit 2 comprises primary conductors 9a, 9b through which the current to be measured flows.

In the illustrated embodiment, the primary circuit unit comprises a first circuit board 22 and a connection portion 20 for connecting the primary conductors to external primary conductors. The connection portion 20 comprises first and second connectors 20a, 20b connected to first and second ends of the primary conductors.

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The circuit board comprises conductive tracks that are electrically connected to electrical terminals of the first and second connectors **20a**, **20b**.

In the embodiment illustrated, there are at least first **9a** and second **9b** primary conductors. The first and second primary conductors may be configured to carry currents flowing in opposite directions such that the magnetic fields generated by the electrical currents flowing in the primary conductors tend to cancel each other out. The primary conductors may in particular carry a current of a same electrical circuit, for instance the positive and negative lines of an electrical circuit. In case of an imbalance in the electrical current in the positive and negative lines the magnetic field generated by the opposed primary conductors is not cancelled and may thus be detected. This may signal a leakage current or other anomaly.

The transducer may be used for detecting a non-zero total current, sometimes called differential current or residual current.

The transducer may also be employed on an earth connection forming a single primary conductor track to detect residual currents in a non-differential operating mode.

The transducer may also be employed for measuring currents in a primary conductor in a closed-loop configuration, whereby a compensation coil is driven by a compensation current to generate a magnetic field seeking to cancel the magnetic field generated by the primary current.

As the magnetic field generated by the electrical current transducer is close to zero in normal operating mode for the various embodiments described above, the magnetic circuit core does not require a large cross-section to avoid saturation.

In an embodiment, the primary conductors comprise circuit traces formed on the first circuit board. A first primary conductor portion **9a** is formed by one or more circuit traces on one or more layers of the first circuit board **22**, and a second primary conductor portion **9b** is formed by one or more circuit traces on one or more other layers of the first circuit board **22**. In the illustrated embodiment, the first primary conductor portion comprises two circuit traces, one on each outer side of the circuit board as best seen in FIGS. **1c**, **3a** and **3b**. The second primary conductor portion comprises two circuit traces positioned on layers positioned within the circuit board between the outer sides, as best seen in FIG. **1c**. Various other configurations may however be provided within the scope of the invention, for instance:

each primary conductor portion may comprise only one circuit trace on one layer of the board, whereby for instance the first and second primary conductor portions are disposed on opposed outer sides of the board, or

each primary conductor portion may comprise a plurality of layers greater than two; or

each primary conductor portion may comprise a circuit trace on an outer side of the circuit board and one or more further circuit traces on a layer within the circuit board;

the circuit traces of the first and second primary conductor portions on different layers may be on alternate layers (i.e. interleaved) such that at least one of the first primary conductor portions is positioned between two second primary conductor portions, and at least one of the second primary conductor portions is positioned between two first primary conductor portions.

The first and second primary conductor portions may thus be formed in any combination of arrangements on different layers of the circuit board.

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In an embodiment, the primary conductor circuit traces comprise a width that extends a major part of the width of the first circuit board, in order to be able to carry a primary current with a relatively high amplitude.

In an embodiment, the primary conductor portions comprise wide end portions **30a** and a narrower mid portion **30b** extending between the end portions. This configuration helps to increase the magnetic flux density concentrated in the magnetic core that encircles the mid portion **30b**. The first and second primary conductor circuit traces may advantageously comprise substantially identical or similar surface areas and similar shapes overlapping each other by more than 80%, seen in a direction orthogonal to the surfaces of the circuit board.

In the case of a differential current measurement, where the first and second primary conductor portions carry currents flowing in opposite directions, the substantially matching and closely positioned overlapping layers are effective in cancelling the magnetic field generated by currents on same amplitude but opposing direction.

In an embodiment, the secondary circuit unit **4** comprises a magnetic field detector **8** that may for instance be in the form of a Hall sensor mounted on a second circuit board **25** and interconnected via conductive circuit traces to a connector **28** comprising terminals connected to the circuit traces on the circuit board. The connector **28** presents terminals **29** for instance in the form of pin terminals at a same mounting side as the terminals of the first and second connectors of the primary circuit unit such that the electrical current transducer can either be mounted on an external circuit board or connected to an external connector, for instance a pluggable connector.

The second circuit board **25** may advantageously comprise a recess or an orifice **26** positioned below the magnetic field detector **8** in order to allow a first end **3a** of the magnetic circuit **3** to be positioned adjacent an underside of the magnetic field detector **8**, another end **3b** of the magnetic circuit being positioned above the magnetic field detector on an upper side. A magnetic circuit gap **7** is formed between opposing ends **3a**, **3b** of the magnetic circuit **3**, the magnetic field detector **8** being positioned in the magnetic circuit gap.

In an embodiment, the secondary circuit unit comprises a compensation coil **10** driven by a feedback loop circuit connected to the magnetic field sensor, configured to generate a magnetic field seeking to cancel the magnetic field generated by the primary current. In the illustrated embodiment, the compensation coil **10** advantageously comprises a winding of conductive circuit trace formed on the second circuit board **25**, the circuit trace encircling the magnetic field sensor. The circuit trace may be provided on a single layer of the circuit board or on two or more stacked layers of the circuit board in order to increase the density and number of windings.

The housing **6** comprises an outer casing **12** and an inner support part **14**. The inner support part **14** comprises a main body portion **16** and a magnetic core support portion **18** hingeably connected to the main body portion via hinge portions **42a**, **42b**. The inner support part is in a preferred embodiment formed as a single integral part, for instance a plastic injection molded part. The main body portion comprises a primary circuit unit lodging **31** in the form of a slot in which the first circuit board **22** of the primary circuit unit **2** may be inserted. The conductive traces carrying the primary current may therefore be accurately positioned within the inner support part **14**. The lodging **31** and primary circuit unit are provided with complementary positioning and fixing elements to accurately position and secure the

primary circuit unit to the inner support part **14** after assembly of the two components.

The magnetic circuit comprises a magnetic core **24** that in an advantageous embodiment is in the form of a thin strip or band of amorphous or nanocrystalline magnetic material. A strip of amorphous magnetic material may be cut from a reel of material and is particularly cost-effective to manufacture. Also, the thin strip of amorphous magnetic material is easily deformable and may be bent to form a generally oval shape as will be discussed hereinafter. The strip of band has a thickness that is preferably less than 0.1 mm, for instance a cobalt based amorphous alloy with a thickness of 0.02 mm. The reluctance of the magnetic core should be lower than the reluctance of the magnetic circuit gap (also called "airgap") preferably at least five times lower, more preferably at least 10 times lower.

The magnetic circuit may be formed by a single thin strip or band of amorphous or nanocrystalline magnetic material, or by two or more strips, stacked upon each other, if needed to avoid saturation of the core for the operating conditions and operating range of the current transducer.

An example of the estimation of the reluctance of the airgap and the magnetic core is shown below for illustrative purposes:

Airgap:

length  $l=10^{-3}$  m, cross section  $A=3\times 3\times 10^{-6}$  m<sup>2</sup>, rel. permeability  $\mu_r=1$

$$R_{M\ gap}=1/(\mu_0\mu_r)\times l/A=1/\mu_0\times 111$$

Magnetic Circuit:

length  $l=0.1$  m, cross section  $A=3\times 0.02\times 10^{-6}$  m<sup>2</sup>, rel. permeability  $\mu_r=10^5$

$$R_{M\ core}=1/(\mu_0\mu_r)\times l/A=1/\mu_0\times 16.7$$

The main body portion **16** of the inner support part **14** further comprises a secondary circuit unit lodging recess **32** within which the second circuit board **25** of the secondary circuit unit is inserted. Fixing posts or latching protrusions or other fixing elements may be provided to secure and position the secondary circuit unit **4** within the lodging recess **32**. The fixing posts **36** ensure also an accurate positioning of the magnetic field detector **8** within the lodging recess and therefore with respect to the inner support part **14**.

The inner support part **14** may advantageously comprise a positioning recess or slot that is formed within the magnetic core support portion **18** but also within the main body portion **16**. The positioning recess or slot **18** is dimensioned so as to receive therein the longitudinal strip of magnetic core such that the side edges of the strip are within the recess and held by sidewalls of the recess. The positioning recess or slot **18** may be provided advantageously with a positioning portion **40** that positions one end of the magnetic core **24** below the magnetic field detector **8**, and in particular within the orifice **26** of the circuit board positioned below the magnetic field detector **8**. The magnetic core end positioning portion **40** has a raised surface such that the magnetic core is positioned within the orifice **26**. The magnetic core **24** may be held within the recess **18** by latching protrusions, or by spot welding edges of the recess during the assembly process, such that they flow over edges of the magnetic core strip.

As best seen in the FIGS. **2a** to **2f**, assembly of the electrical current transducer is illustrated. Referring first to FIGS. **2a** and **2b**, the primary circuit unit **2** and in particular the first circuit board **22** may be inserted into the primary circuit unit lodging **31** of the inner support part **14**. Before

or after this operation, the magnetic core **24** may be inserted in the positioning recess of the magnetic core support portion **18** and securely fixed therein, for instance by ultrasonic welding of wall portions bounding the recess such that the material flows over edges of the magnetic core strip and secures it within the positioning recess.

The secondary circuit unit **4** is inserted in the secondary circuit unit lodging **32** of the main body portion **16** of the inner support part **14** as best seen in FIG. **2c**.

The magnetic core support portion **18** of the inner support part may then be pivoted around the hinge portions **42a**, **42b** such that the second end **3b** of the magnetic circuit strip bends around the main body portion **16**, thus going through a 360° rotation, until the second end **3b** is positioned over the magnetic field detector **8**. The second end **3b** of the magnetic core positions over and above the first end **3a** of the magnetic core forming the magnetic circuit gap **7** therebetween. The magnetic core support portion **18** may comprise a latch **44a** that engages a complementary locking shoulder **44b** in the fully rotated position, as best seen in FIGS. **2d**, **2e** and **1c**. In the illustrated embodiment, the magnetic core support portion **18** is provided with two hinge portions **42a**, **42b** that allow the end of the magnetic core support portion to swivel around 360° while an intermediate stiff portion **42c** rests against a surface of the main body portion **16**.

Once the magnetic core support portion **18** has been folded over by 360° and latched to the main body portion **16** as shown in FIGS. **2d**, **2e** and **2f**, a magnetic shield **5** may optionally be inserted over and fixed to the inner support part **14** overlapping the magnetic circuit **3**. This is best illustrated in FIGS. **2f** and **1c**. The magnetic shield may advantageously be made of a magnetic material and serves to absorb magnetic flux external to the transducer and shield the magnetic circuit from external magnetic fields. The magnetic shield **5** may advantageously be in the form of a generally U-shaped part made of soft magnetic material in a sheet form that is stamped and formed, which is particularly cost-effective to manufacture.

The inner support part **14** may advantageously be provided with sidewall portions **43** that engage with side edges **13** of the lateral branches **5a**, **5b** of the magnetic shield so as to position and secure the magnetic shield to the inner support part **14**. The side edges may comprise barbs that dig into the sidewall portions **43**, or other means to secure the shield to the inner housing **14**.

In a subsequent step, the outer case **12** may be positioned over the inner support to cover the magnetic circuit and the magnetic shield therein.

In an advantageous embodiment, the outer case may be provided with a base **12a** and a cover **12b** connected together by a hinge **12c**, for instance an integrally formed hinge, allowing the cover to swivel 180° degrees around and latch onto the base **12a** via latching elements **12d** as illustrated in FIGS. **2f**, **1c** and **1a**.

#### LIST OF REFERENCES IN THE FIGURES

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electrical current transducer 1  
primary circuit unit 2

primary conductors 9a, 9b  
circuit traces  
narrow mid portion 30b  
wide end portions 30a

-continued

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connection portion 20	
first and second connectors 20a, 20b	
first and second terminals 21a, 21b	
first circuit board 22	
magnetic circuit 3	

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first end 3a	
second end 3b	
magnetic core 24	
strip/band	
of amorphous magnetic material	
magnetic circuit gap 7 (air gap)	
secondary circuit unit 4	

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magnetic field detector 8	
hall sensor	
compensation coil 10	
second circuit board 25	
orifice 26	
connector 28	
magnetic shield 5	

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lateral branches 5a	
end branch 5b	
housing 6	

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outer casing 12	
base 12a	
cover 12b	
integral hinge 12c	
latch 12d	
inner support part 14	
main body portion 16	
primary circuit unit lodging 31	
slot	
secondary circuit unit lodging 32	
fixing posts 36	
magnetic core support portion 18	
positioning recess/slot	
magnetic core end positioning portion 40	
hinge portions 42a, 42b	
latching portions 44a, 44b	

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The invention claimed is:

1. A current transducer including a housing comprising an outer casing, a magnetic circuit core configured to encircle at least one primary conductor, and a magnetic field detector positioned in a magnetic circuit gap of the magnetic circuit core, wherein the housing further includes an inner support part comprising a main body portion and a magnetic core support portion and the magnetic circuit core is in the form of at least one strip of amorphous material with a magnetic reluctance smaller than the reluctance of the magnetic circuit gap and having a thickness less than 0.1 mm supported on the main body portion and magnetic core support portion, the magnetic circuit gap being formed between overlapping ends of the strip.

2. The transducer according to claim 1, wherein the main body portion and the magnetic core support portion are

connected via hinge portions configured to allow the magnetic core support portion to wrap around the main body portion.

3. The transducer according to claim 2, wherein the hinge portions are flexible webs integrally formed with the main body portion and magnetic core support portion.

4. The transducer according to claim 1, including a primary circuit unit comprising a first circuit board lodged in the main body portion of the inner support part and at least one conductive trace on the first circuit board constituting a portion of the at least one primary conductor.

5. The transducer according to claim 4, wherein the first circuit board comprises a plurality of circuit traces on different layers of the first circuit board, forming said at least one primary conductor.

6. The transducer according to claim 5, comprising two primary conductors configured to carry currents flowing in opposing directions, wherein the transducer is configured for a differential current measurement.

7. The transducer according to claim 6, wherein the circuit traces on different layers overlap each other by at least 80%, seen in a direction orthogonal to the first circuit board.

8. The transducer according to claim 4, wherein said one or more conductive traces of the one or more primary conductor portions comprise a mid-portion of narrower width than end portions.

9. The transducer according to claim 8, comprising a secondary circuit unit comprising a second circuit board lodged in the main body portion of the inner support part, the magnetic field detector being mounted on the second circuit board.

10. The transducer according to claim 9, wherein the secondary circuit unit comprises a compensation coil in the form of windings of a circuit trace on one or more layers of the second circuit board around the magnetic field detector.

11. The transducer according to claim 10, wherein the second circuit board comprises a recess or orifice below the magnetic field detector configured to allow one end of the magnetic circuit core to be positioned therein.

12. The transducer according to claim 1, wherein the magnetic core support portion comprises a slot in which the magnetic circuit core is positioned.

13. The transducer according to claim 1, comprising a magnetic shield having a U shape inserted over the magnetic circuit core and supported on the main body portion of the inner support part.

14. The transducer according to claim 1, wherein the magnetic circuit core has a thickness of less than 0.03 mm.

15. The transducer according to claim 1, wherein the magnetic core support portion and main body portion comprise complementary latch portions to fix together the magnetic core support portion and main body portion in a wrapped around position.

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